ENGINEERING CASE LIBRARY

ECL 219

DIFFICULTIES WITH MODULAR HOUSING (A)

Aharon Klein, Chief of Structural Engineering and Executive Vice President of Omega Industrialized Homes Inc., was faced with a problem. After developing a modular housing concept, and structurally testing a full scale two story unit, the State Housing authorities informed him that they would not accept the test for any further approvals.

NOTE: All names have been disguised.

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DIFFICULTIES WITH MODULAR HOUSING (A)

Aharon Klein was an architectural graduate of a large midwestern school and had received a graduate fellowship to study strucutral engineering at M. I. T. After receiving his Master's degree he worked for a major architectural firm in New York City. Later he moved to J. J. Judd and Associates in Rivercity where he eventually became head of the structural department.

After 12 years of working for large consulting firms, Aharon moved to Omega Industrialized Homes Inc., a small manufacturing operation. Aharon's association with Omega started innocently enough. One day one of Aharon's associates mentioned that Jack Latto of Omega Industries, Inc., was looking for some way to diversify his business interests and wanted to talk to an architect or an engineer about industrialized housing systems. Latto was chairman of the board and president of Omega Industries, Inc., a supplier of mechanical products to the building trade.

At their first meeting, J. Latto told Aharon that he wanted industrialized houses that didn't follow traditional building methods and that could be manufactured in a factory with a minimum of on-site labor. Rivercity, located in the middle of the east coast urban corridor, would be an ideal place to manufacture such houses.

A few weeks after the first meeting Aharon presented Latto with architectural sketches showing the various ways standard modules could be assembled into different attractive housing units. Latto liked what he saw and contracted with Aharon to produce additional sketches and work out further details.

The concept of modular home construction was not new. (Exhibit A-1). Other manufacturers were already in the business. Most were using conventional modes of construction adapted to the factory. A survey of these showed that they were having problems because wood has a tendency to warp which restricted construction tolerances to approximately $\pm 1/2$ inch.

Jack Latto did not want to become just another modular home manufacturer. He wanted something that would be an advance in housing construction, something that was not so "way out" as to be impractical or present development difficulties, but something that would offer price advantages in the long run. At one of their meetings, Jack Latto, Aharon Klein, and a civil engineering professor from M. I. T. who consulted

for Omega Industries evolved their fundamental approach to the design of housing modules. The heart of the system was to be a light gage steel frame. This frame was to be the principal load bearing system onto which everything would be hung. (Exhibit A-2)

Once the decision was made to make the modules with a steel load bearing frame other advantages quickly became apparent. The steel frame made it possible to move the modules on the highway without the use of flatbed trucks. By attaching simple wheels directly to the frame, the module could be hauled on the highway without flatbed trucks. The lower profile thus achieved made it possible to have modules with pitched roofs that cleared most highway underpasses. As Aharon said, "without that carrier concept, we couldn't ship to many areas where we do today."

The steel frame permitted greater versatility for module arrangements. Since none of the walls are load bearing, the walls could be omitted to give any arrangement desired without weakening the structure. With the steel frame the modules could be set on simple drilled pier foundations instead of full foundations. Attachment of one module to the other or to the piers could be accomplished by field welding at prescribed attachment points.

Production was also simplified. Once the frame was fabricated, casters could be attached to the module to move it from station to station in assembly line fashion without complex transfer machinery.

With the basic concept established, Jack Latto decided that Omega Industries would go into the modular housing business and that a prototype should be built. Still working for Omega as a part-time consultant, Aharon turned to detail design of the prototype.

Of the prototype, Aharon says, "I did only rough computations up to this point. I didn't go deeply into the analysis because many of the details were being developed as we produced the prototype. I did spend considerable time on the design of the joints. I was determined to get away from bolts or mechanical fasteners on the frame and to stick to welding. The welding on the prototype and test specimens was done by Omega's regular production personnel. We had a few problems but by testing and redesigning we resolved them. This is where I got to know the company much better."

One of the more critical problems that Aharon wrestled with at this time was how he was going to attach the 2 x 4 wood

studding and the plywood wall panels to the steel frame. The system had to be inexpensive and simple, otherwise the economic advantages of his steel frame would disappear. Where the steel frames were 14 ga. and thinner, he could use case-hardened nails but for heavier gages the nails would not do.

He looked far and wide for something better than drilling a hole and fitting a screw. Finally he found patented "TEKS" fasteners (Exhibit A-3) used in the mobile home industry for attaching wooden sub-floors to the steel frame. "Actually, without that little screw, we wouldn't be able to use our system," commented Aharon.

The prototype proved the modular concept and demonstrated that the system could be made to work. When Jack Latto announced that Omega Industries would set up a division to produce the modular system, Aharon's recommendation was, "You're getting into a field where you are going to need a full time architect or engineer and you should hire one." Latto in response offered Aharon Klein the presidency of the new division.

"I think what finally convinced me to join Omega was that it was a chance to do something new and head a company. I really believe that industrialized housing is the way things have to go. What I had been doing in structural engineering was fine, but it was doing things the way they've been done for the last 50 years. This was an opportunity to put together a design and production team. I was given free rein to hire anyone I wanted."

Later the modular housing division was separated from Omega Industries and became a separate publicly owned company, Omega Industrialized Homes Inc. Jack Latto became President and Chairman of the Board. Aharon Klein became Executive Vice President. As Executive Vice President, Aharon is completely responsible for the technical and operational side of the business while Jack Latto concentrates on the financial aspects.

With a prototype house built and, to a large degree, the details of construction developed, Aharon put together his team for designing and manufacturing. At this point they were three: an architect to do detail interior and exterior design; an industrial engineer to plan production; and Aharon who acted as structural engineer and coordinator.

A cost analysis showed that the modular house would cost a little more than one of conventional wood framing, but in

the long haul it was felt that wood prices and on-site labor were bound to go up faster than steel prices and shop labor. It was also felt that with experience further short cuts and efficiencies could be developed which would lower the cost of the modules until the price was lower than conventional construction. Although these were speculations, they were based on well established trends.

The basic module was designed to be 12 ft. wide (maximum allowed for road clearance) by 9 ft. high and from 16 ft. to 36 ft. long. The structural element was the shop fabricated steel space frame. The modules were to be assembled entirely in the factory; frame, walls, carpets, plumbing, kitchen, everything except the furniture. The finished modules were joined by welding on-site. The modules could easily be manufactured for assembly in any desired pattern. Any wall could be omitted between modules to provide a multi-module living space. (Exhibit A-4)

The units are not produced on a true "mass" produced basis. Usually they are produced in lots of 100 at a time on an assembly line. The modules move on casters from station to station for different operations. A module spends about two hours at each of approximately ten stations and is completed in a little over 20 hours. A basic house is comprised of four modules, thus would be fabricated in the shop in 80 hours. The house is assembled on-site from the modules in two days.

But that was in the future. Aharon had only a design, a prototype house, and a staff of two to plan production. His immediate concern was to find some business. Fortune smiled on Omega. One Saturday afternoon, Aharon and his staff were in the office, "we were sitting here making theoretical plans and plant layouts. We had no idea of how we were going to break into the business. We had talked to a number of housing developers and, although they were interested, nobody actually thought we would go into production." Into this late Saturday afternoon conference walked Ernie Blumstein, a developer and owner of the Cherry Development Company. He said he had heard about Omega's idea and was interested in finding out what they could do. Cherry Development had an F. H. A. Commitment for a 62 unit townhouse development in Triplecreek, a nearby suburb.

Ernie Blumstein had no interest in being a conventional builder. He wanted to do something different. Aharon showed Ernie what they had to offer and how this could satisfy Ernie's desire to do something different. He showed him the prototype. Ernie liked what he saw and signed a

contract with Omega to build the units for Cherry Development even though he knew they didn't even have a factory to build them. The contract was dependent on Omega obtaining approval from F.H.A. and the local building agencies. Since that Saturday afternoon, Ernie Blumstein and Omega Industrialized Homes Inc. have had a close and mutually beneficial association.

Omega had its first order and the search started for a suitable location and plant to start production. The search took several months. They found and moved into a production facility in Triplecreek in April. While the search and negotiations for the new plant were going on, Aharon was busy trying to get approval for his modular houses.

The state had recently set up the Department of State Housing and Regional Planning to approve housing designs. The intent was to provide uniformity in building standards throughout the state. When Aharon sent his plans to the department, they returned them stating that they weren't organized yet and that in a few months they would be ready to check plans. They suggested that until then he get approval from his local housing official. For the first project in Triplecreek, this was simple. The city engineer simply approved the plans because they had a professional engineer's stamp. Besides he looked at the steel frame of the prototype and concluded that it was stronger than conventional construction. Although his approval solved Omega's immediate problem, the industrialized housing concept required that approval be on a much wider basis and Aharon knew he would eventually have to go back to the Department of State Housing and Regional Planning.

Most housing developments and the Cherry Development project in particular are built under F.H.A. secured loans. F.H.A., therefore, had to approve the construction. The local F.H.A. administrator, in this case, the regional strucutral engineer, had to authorize that the building was insurable by F.H.A., as far as structural integrity was concerned, before building could commence.

As Aharon said, "After all, they insure mortgages up to 30 years. If anything happens, F.H.A. ends up owning the unit. They need to be sure that it is sound. We are the ones asking for the approval. It is a privilege, not a right."

There are no F.H.A. specifications. As a guide, Aharon was given a list of approvals which had been given in the past. Aharon prepared extensive detailed calculations of the structural integrity of the module under various loads and

conditions using the best available codes and specifications, and submitted these to F.H.A. After much discussion, the regional structural engineer said, "Look, we want a test. We won't accept computations. We don't care how many engineering standards you use. Part of our requirements is a test. If you are really serious about getting into this kind of building, you should be able to afford it." Aharon felt that the F.H.A. engineer was going to make certain that as long as he was in that position, anything he approved would be physically tested, and he had the authority to do so.

The discussion then turned to the kind of test that should be made. After some discussion, the F.H.A. engineer explained, "Sooner or later it will have to boil down to some basic number. What's that number going to be? Let's do a test to see how much lateral load your finished two story building can take."

Aharon returned to his plant wondering how he was going to test a two story, full-size building. He was certain that to get the maximum information he should test one each of the different module configurations.

Modular apartment building by Stirling-Homex illustrates the probable trend in home building. Sections are factory built, transported to the building site, and simply stacked in place. Assembly line techniques significantly reduce construction costs.

* Photos reprinted from "Industrialized Housing - A New Kind of Cave" Machine Design, Oct. 1971, Copyright 1971 by the Penton Publishing Co., Cleveland, Ohio.

Finished townhouse, assembled on site from factory-built wood modules.

EXHIBIT A-1

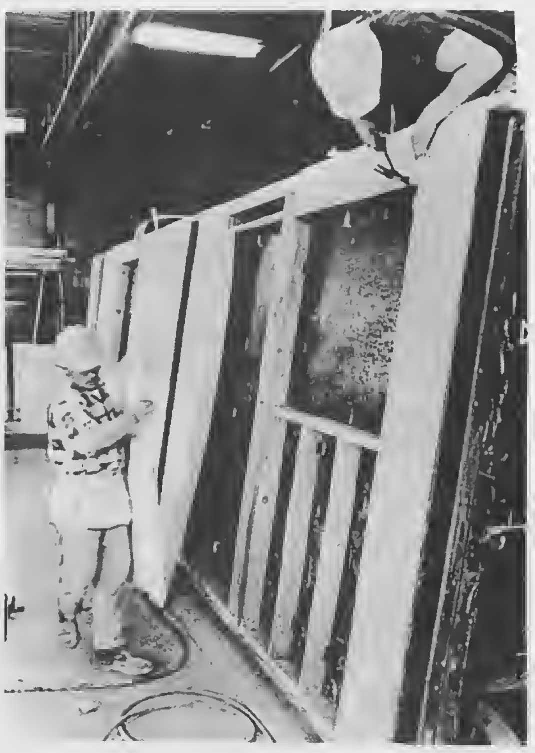
Casewriters Note:

These photos do <u>not</u> represent the modular housing discussed in the case. They are simply to illustrate the state of the art.

Houses on the move. Completed townhouse modules travel by rail to the construction site. In this operation, one train carried modules for 14 townhouses. Cranes position the modules like building blocks. Builder is Stirling-Homex.

To fabricate the floor, precut components are set into precision forms at the beginning of the production line.

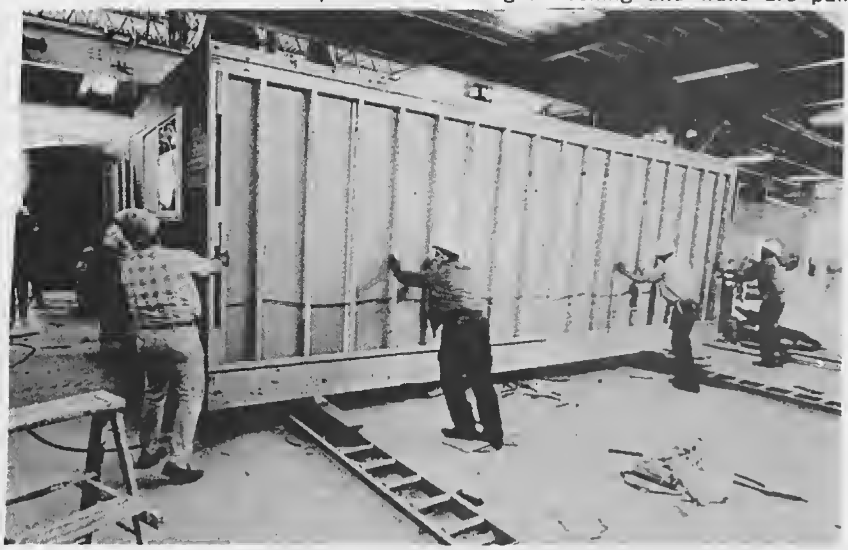
Photos illustrate factory manufacture of a townhouse module by Stirling Homex. Wood is the basic material used.



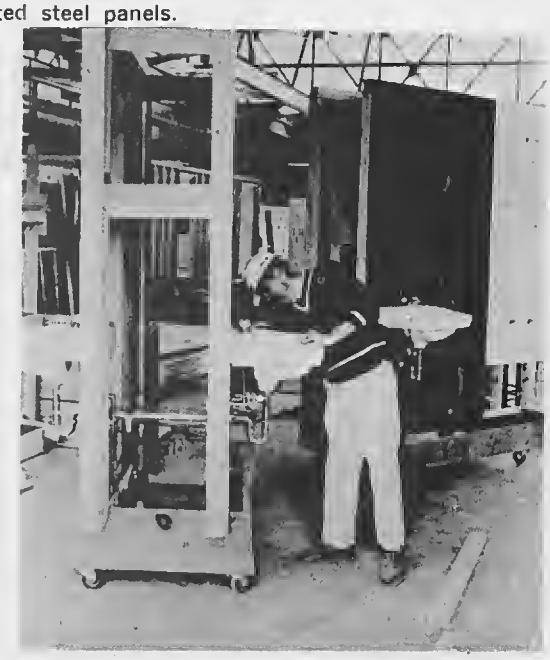
Wall units are built on color-coded jigs.

EXHIBIT A-1 (continued)

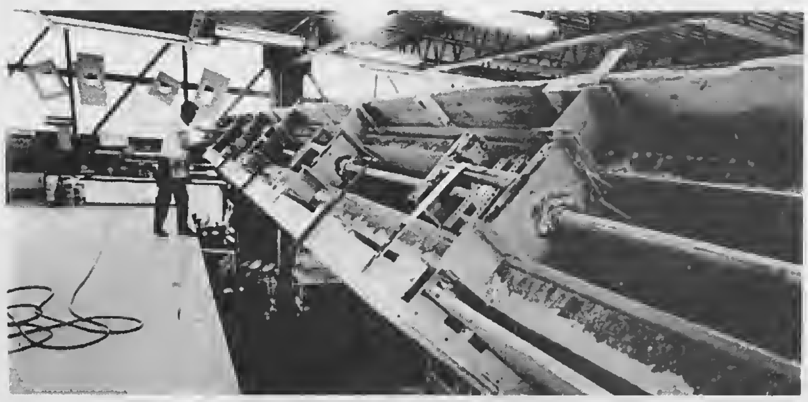
Entire kitchen is factory assembled, including all major appliances, in this Republic Steel design. Ceiling and walls are painted steel panels.



The basic module is formed from wall panels joined to the flooring. The assembly rolls along the production line on tracks.

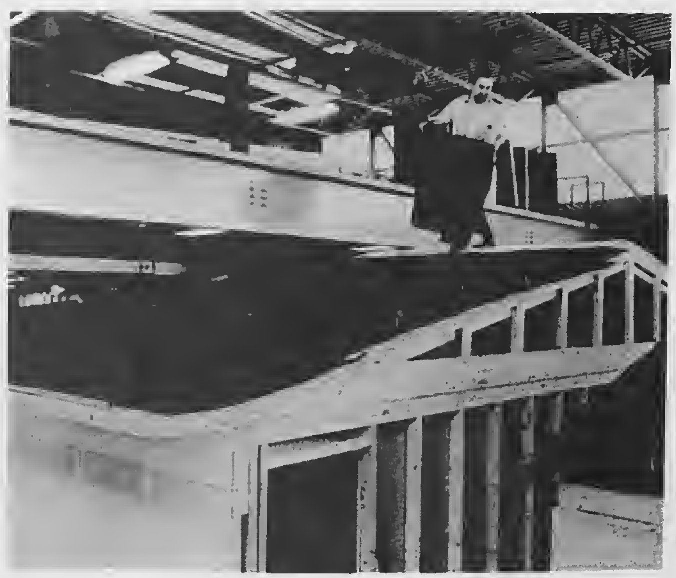


Bathroom fixtures are installed in separately constructed cores which are set into the modules on the main production line. Kitchen cabinets and closets are handled similarly.

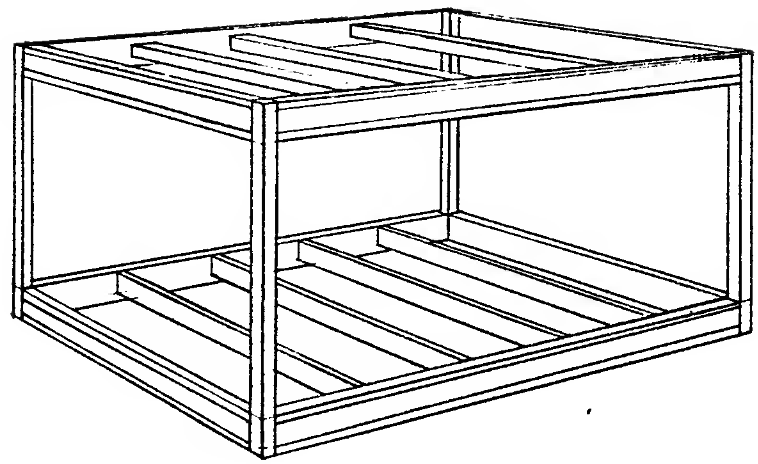


Module ceilings are made upside down in giant forms located on an upper level of the factory. When completed, the ceilings are turned over by machine and set atop the modules on the moving production line.

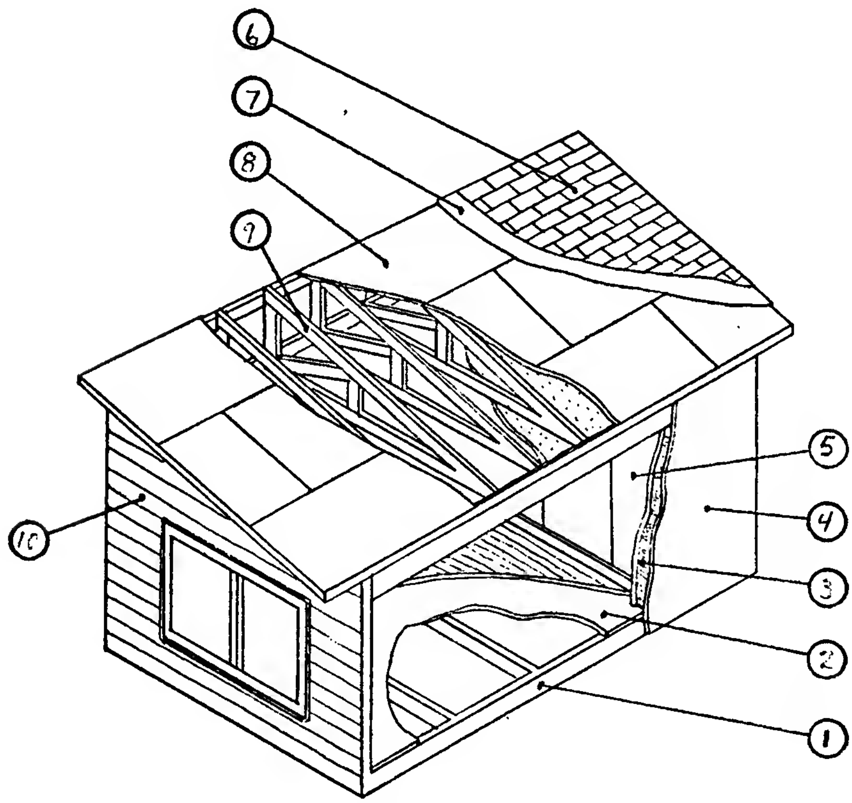
EXHIBIT A-1 (continued)



Midway down the production line, shingles are placed on the roof top. A substantial overhang remains at the roof edges to allow for the joining of the town houses at the home site.



1. Steel Frame



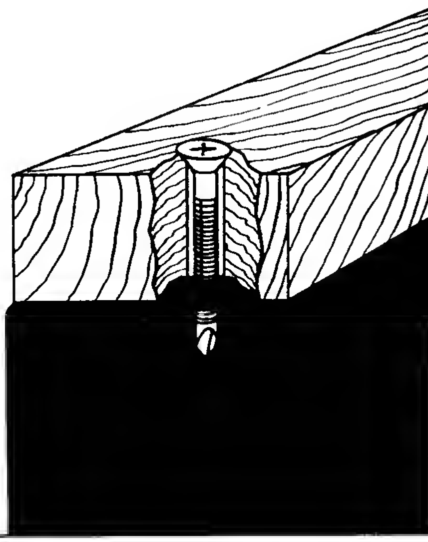
TOP MODULE CONSTRUCTION

1. Steel Frame
2. Plywood Subflooring
3. Insulation
4. Exterior plywood siding
5. Drywall
6. Shingles
7. Underlayment
8. Plywood Roof Sheathing
9. Prefabricated roof trusses
10. Metal Siding

EXHIBIT A-2

2 x 4 HEADERS TO PURLIN

HEADER TEKS®



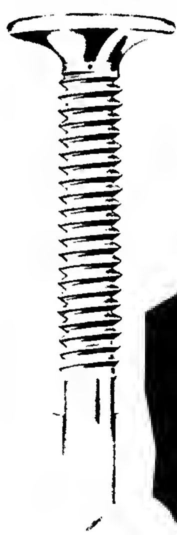
U.S. PATS. #3,125,923 and #3,358,548

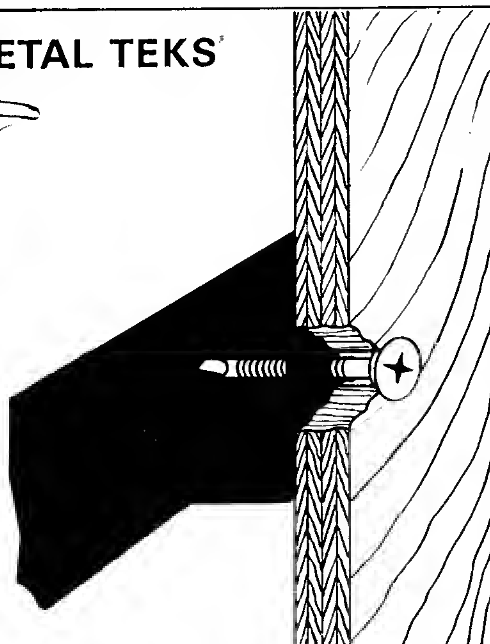
Header Teks utilize the reamer wing principle but also have a special head design so that they countersink and seat flush in wood. The Header Teks is designed specifically for attaching wood 2 x 4's to a purlin as a header for partition walls, or as a nailer. The wings ream out a clearance hole in the wood so that the threads cannot form. When the metal structural piece is drilled, the reamer wings strike the steel, break off and then the threads form in the drilled hole. Header Teks drill and ream the wood and then drill and tap the steel in one single action. They eliminate the need for separate drilling of holes, and for bolt and nut running.

The Header Teks is a 12-24 x 2½" Phillips flat head reamer Teks /4, plated.

PLYWOOD OR FIRRING TO METAL

PLYMETAL TEKS®





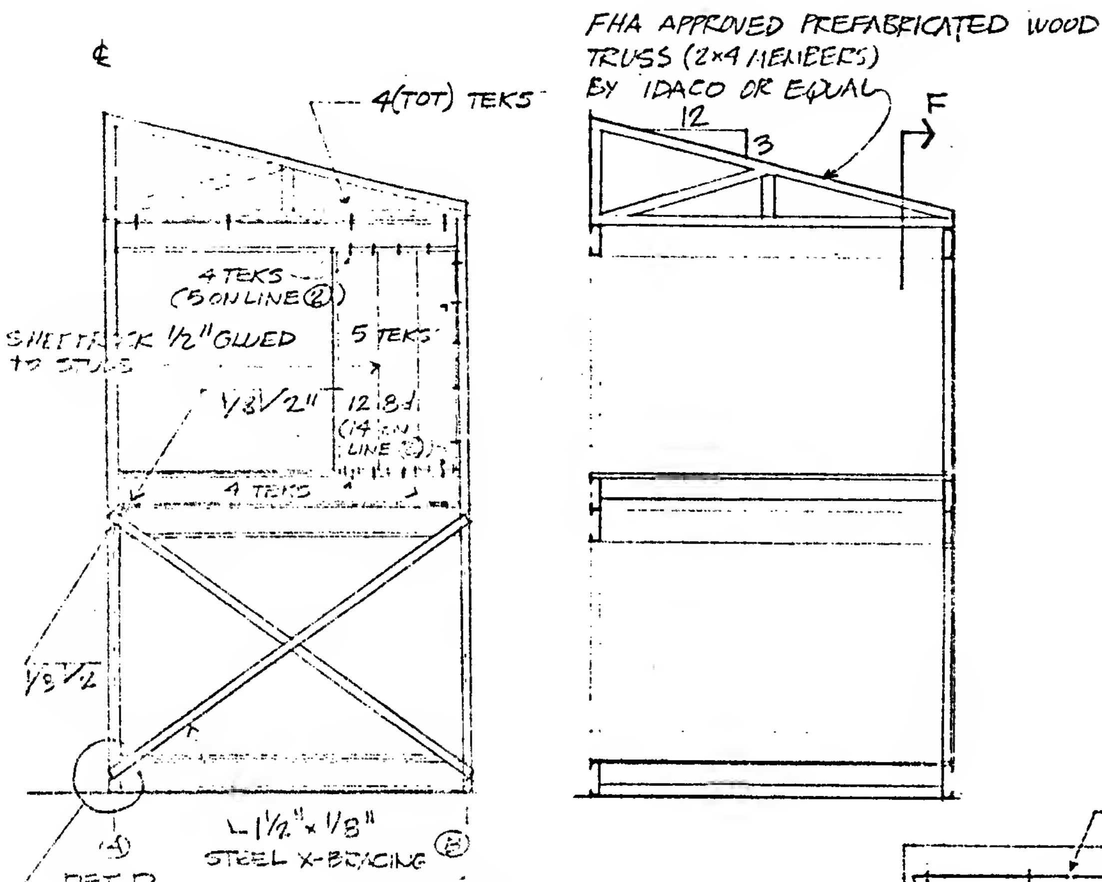
U.S. PATS. #3,125,923 and #3,358,548

The Plymetal Teks is designed for attaching plywood or wood up to ¾ inch thick to steel framing members without pre-drilling. The Plymetal Teks drills, taps, fastens and countersinks into the plywood or firring in one fast operation. For heavy plywood applications reamer wings are incorporated in the fastener. The specially designed wafer head provides a good bearing surface and yet seats flush in the plywood to achieve an excellent finished appearance. Standard Plymetal Teks are available in the following sizes:

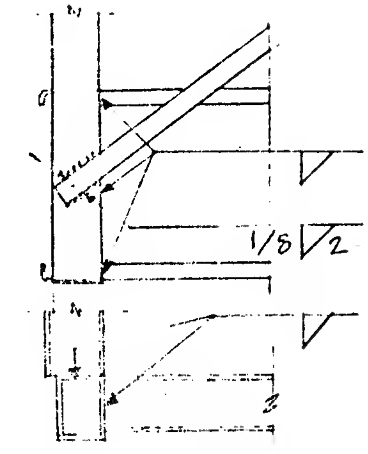
Plywood Thickness	Framing Member		Fastener Size and Length	Phillips Bit Required
	Metal Gauge	Decimal Thickness		
¼"*	18—8	.050 — .175	10-24 x ¾"	#2
½"*	18—8	.050 — .175	10-24 x 1"	#2
⅝"	18—8	.050 — .175	10-24 x 1 5/16"	#2
¾"	18—8	.050 — .175	10-24 x 1 7/16"	#2

* "Wings" not required

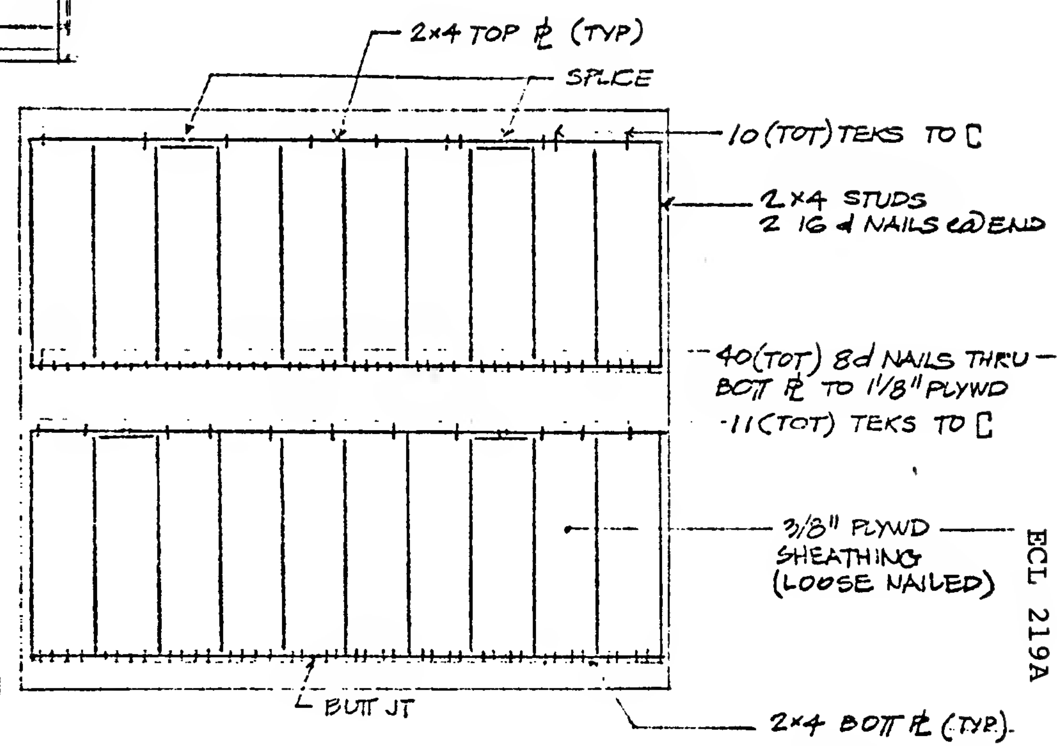
EXHIBIT A-3



WEST ELEVATION



DETAIL D



SECTION F
LOOKING SOUTH

FOUR MODULE TWO STORY PROTOTYPE
USED FOR FHA APPROVAL TESTS
MODULES SYMMETRICAL EXCEPT
AS NOTED

EXHIBIT A-4

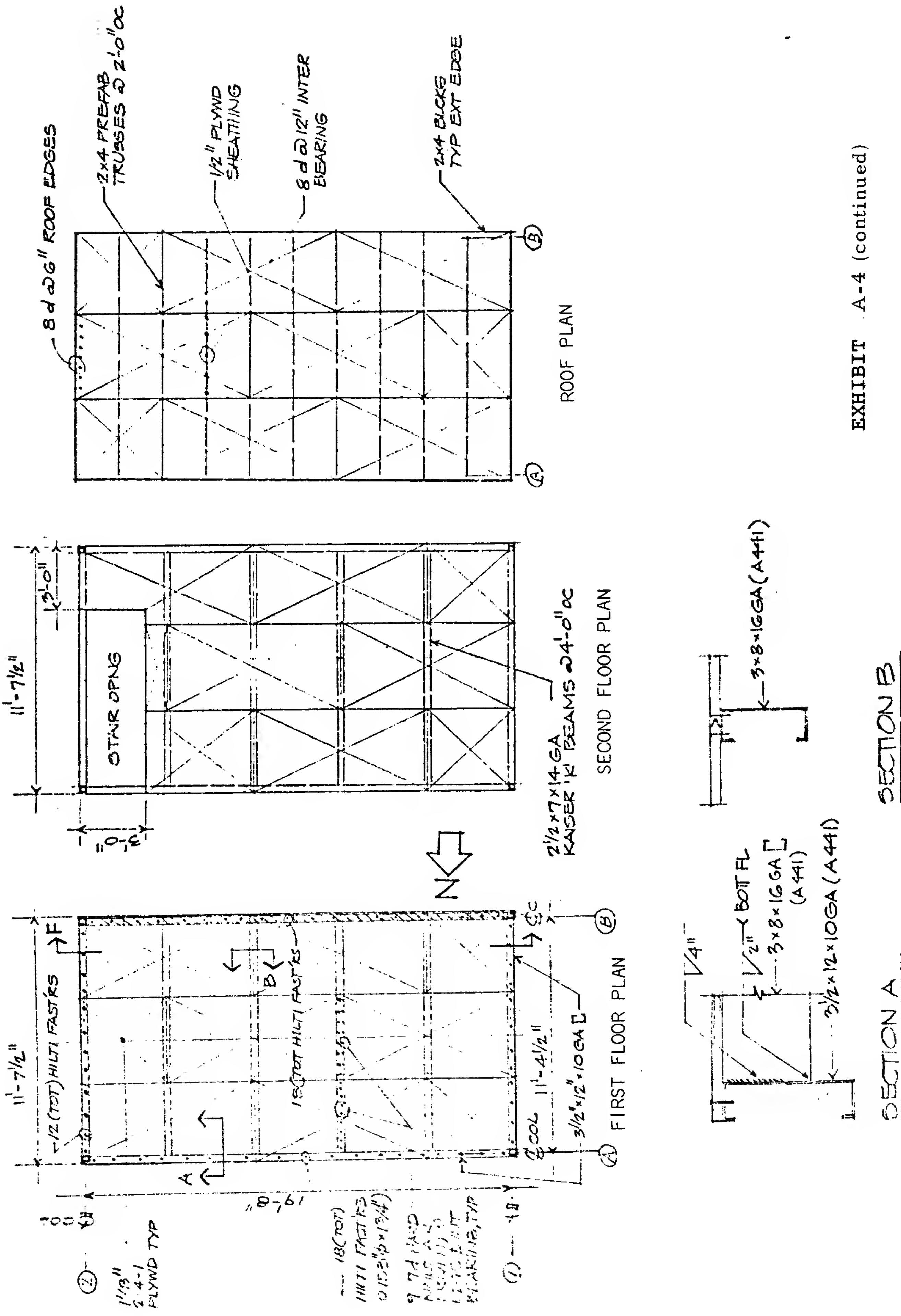
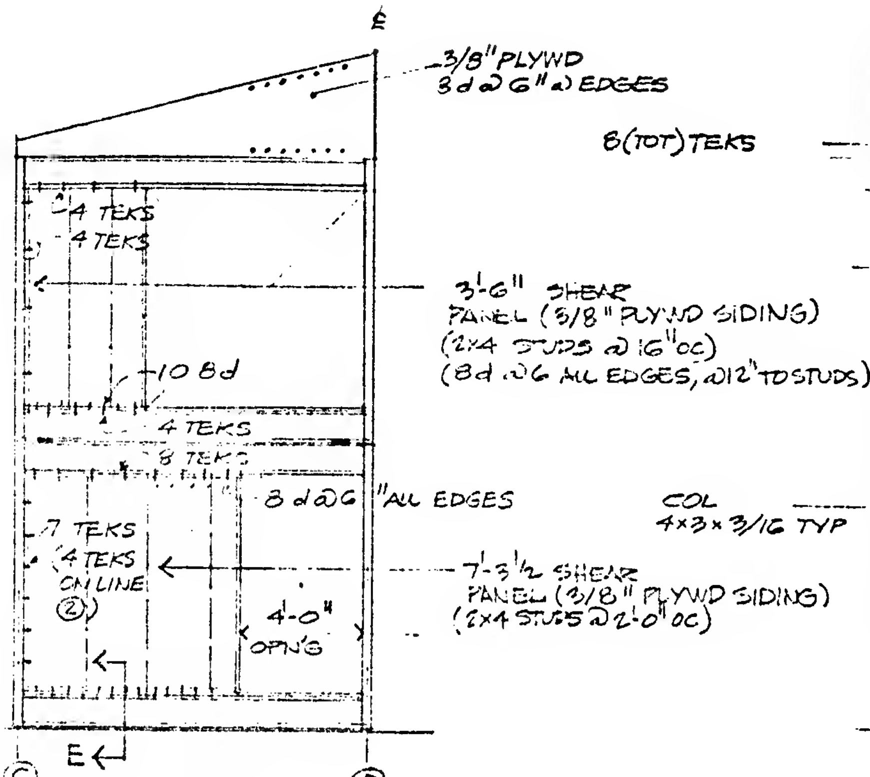
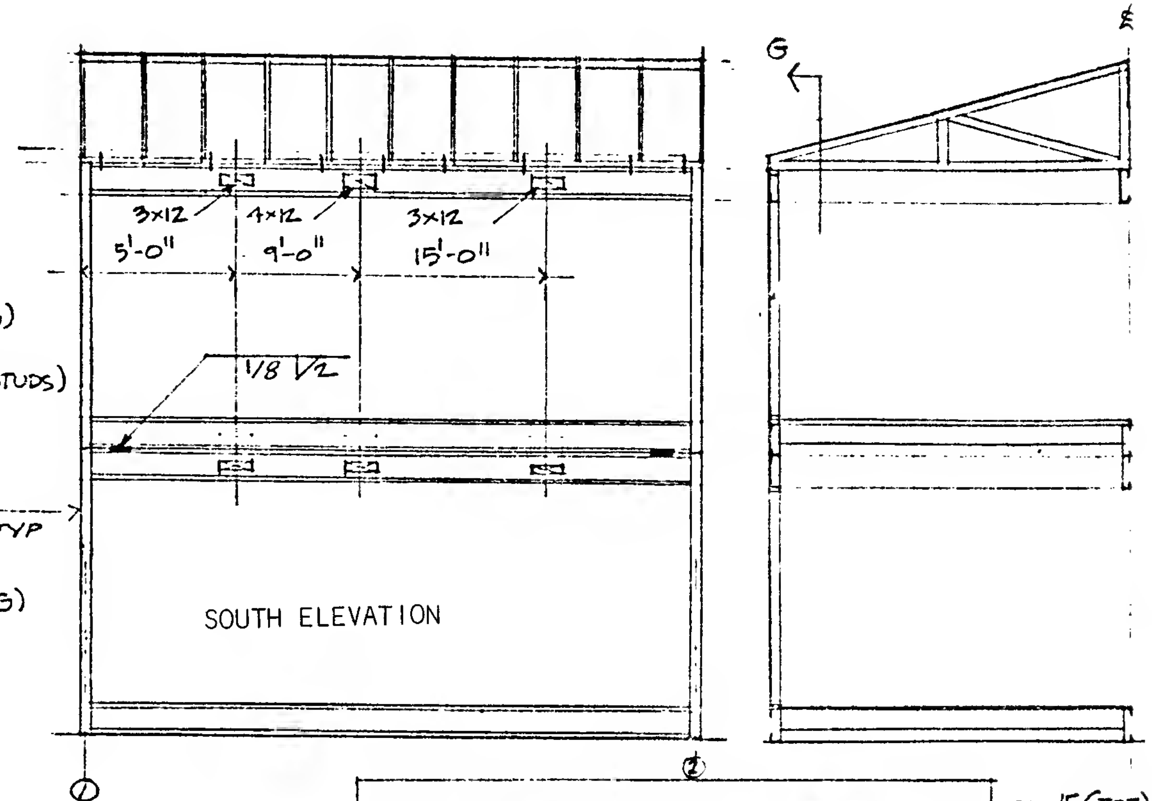


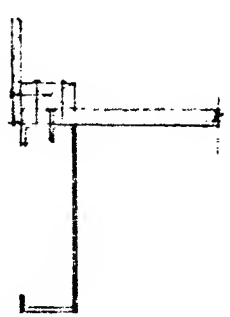
EXHIBIT A-4 (continued)

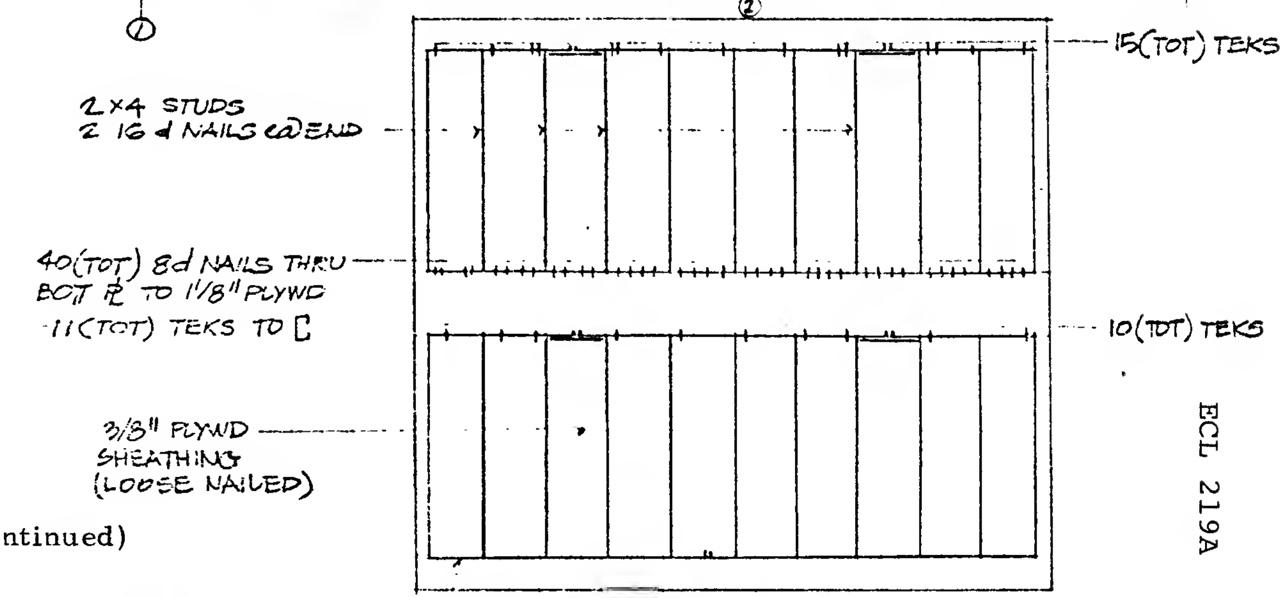


WEST ELEVATION



SOUTH ELEVATION


DETAIL E



SECTION G
LOOKING NORTH

EXHIBIT A-4 (continued)

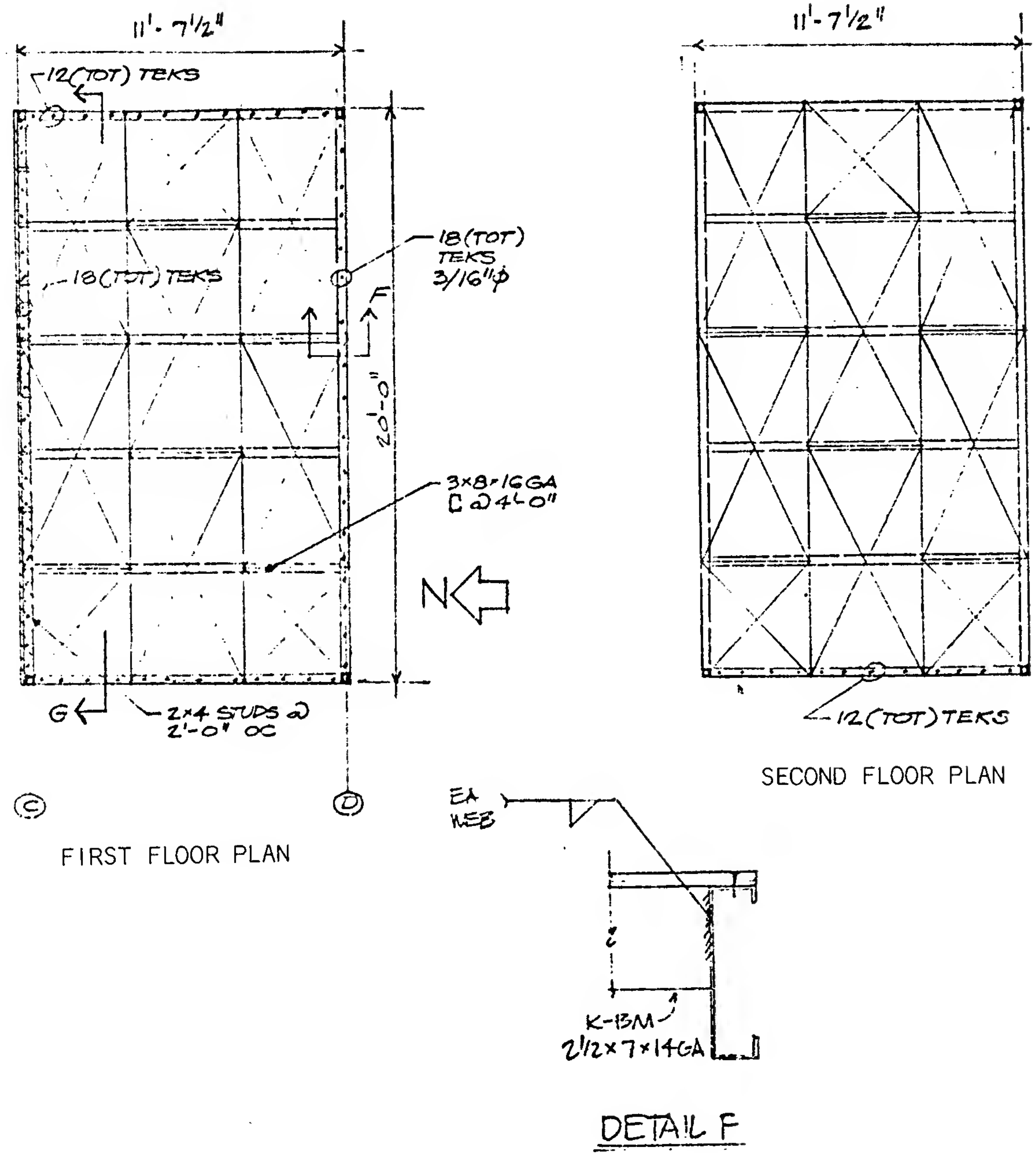


EXHIBIT A-4 (continued)

DIFFICULTIES WITH MODULAR HOUSING (B)

For the test required by F. H. A., Aharon used four housing modules in a two-story configuration mounted back to back (Exhibit B-1). These were mounted on foundations so that there was an eight inch space between them. Between the sections he placed a fabricated polyvinyl bag which was pressurized with air to give a uniform lateral pressure on the outer walls. The live loads were produced by placing iron weights on the floors of the modules.

The modules were of various construction, with diagonal bracing, with shear panels of plywood and with cutouts in the worst possible places expected in service. The tests were started with all the walls in the finished condition, thus the tests would not only reflect the strength of the steel frame, but provide information on the whole method of construction, particularly the special panel fasteners being used.

Before undertaking the tests, Aharon carefully computed the capacity of the steel frame based upon plastic yielding. He had agreed with F. H. A. that they would test to the ultimate strength. His calculations indicated that permanent deformation would start in the frame when the lateral pressure reached 30 lbs/ft^2. The structure had been fitted with displacement gages throughout so that deflections and permanent set could be recorded.

On the first test, the pressure in the polyvinyl bag was raised slowly to approximately 30 lbs/ft^2. Careful inspection showed that there was no sign of failure. The pressure was increased gradually to approximately 50 lbs/ft^2. At 50 lbs/ft^2 the nails began to deform and pop out of the wood. Failure was in the plywood, not in the steel frame being tested. The plywood walls were stripped from the frame. The test was continued on the steel frame without the plywood shear walls.

Once more the lateral pressure was raised to 30 lbs/ft^2. The frame was watched closely. At the ultimate load predicted by calculations everything was still sound. There was no indication of plastic failure. Aharon was pleasantly surprised with how well the welds stood up. He had fully expected that something might go wrong with the welding.

The load was increased steadily to 50 lbs/ft^2 until finally Aharon decided a plastic hinge must have developed. The stresses should have been way past the elastic limit. He

had the load released and to his surprise the structure returned to its original position. The gages showed absolutely zero permanent set.

The results were reported to F. H. A. who immediately gave approval for up to 30 lbs/ft^2 lateral load. This became the magic number.

Aharon was intrigued by the fact that the structure did not show any permanent set even when loaded far beyond the predicted ultimate load. He had some of the frame material tested. It had a yield strength of 60,000 psi. The design specifications for the tubular steel columns call for a minimum yield of 36,000 psi. This was the reason for the excess capacity. Aharon filed this away for future use. He couldn't depend on always having this high yield strength in his steel sections, because economics dictated that he buy steel on the basis of price, but he felt that some day, if the higher strength was needed for such things as modular units for multi-story buildings, he could specify a better grade of steel and use it with confidence on the basis of the tests he had just performed.

The tests took three weeks and cost approximately $15,000. Because there wasn't any permanent set in the modules, they were salvaged and are now used for the accounts offices at the Triplecreek plant. Although forced to make the test, Aharon feels that it was money well spent. Not only did he get F. H. A. approval, but it gave him experience with his design, and verifiable confidence in the structure. It also gave Aharon additional information on elements of the modular construction not readily assessed by computation such as, the method of attaching the wall and floor panels, the reliability of the "TEKS" fasteners, and the soundness of the welding.

With F. H. A. approval, Omaga now had a customer. They moved into their new plant in April. The module floor plans were changed to reflect Ernie Blumstein's requirements. Production of the units got under way.

Because the units were to be transported on simple wheel axles attached directly to the module frame (Exhibit B-2), without springing or shock absorbers, Aharon was worried about what would happen during delivery. He was particularly concerned about how the sheet rock used on inside walls would behave. As soon as a set of axles was received, a module was sent out on a road test. After traveling several hundred miles over various types of terrain, the module returned and was in perfect condition. There were no signs of cracks or deterioration of any kind.

By now the Department of Housing and Development was ready to undertake approvals. To get approval, Aharon made revised computations incorporating the results of his tests and submitted them. The computations were immediately returned. They were not on the right size paper and they had to be redone before they would be considered. The computations were copied onto the required paper and resubmitted with confidence.

Aharon was not apprehensive about obtaining state approval. He had carried out extensive computations and had a set of tests on a full size building to prove his computations. He requested that since his tests verified the computations on his longest module, that he be given approval for this module and all modules shorter than this.

But life is not that simple!

INTRODUCTION

The system tested and analyzed in this report is designed to be used in one and two story combinations.

The proposed use of the system would include the utilization of diagonal bracing or plywood shear panels in various arrangements, in modules 12' wide x 24' long.

It is demonstrated by test and theory that a two story structure without any shear panels would withstand a wind load of 30 PSF with a safety factor of 1.66.

However, it is proposed to always either provide diagonal bracing or shear panels in areas equal to approximately 1/3 of the exterior wall area in the critical direction.

Under these conditions, the safety factor against ultimate strength for a wind load of 30 PSF varies from 1.8 to 2.46.

The corresponding lateral acceleration from seismic action is 35% g (corresponding to 30 PSF wind), and the acceleration to cause yielding of structure is at least 1.66 x 35% g = 58% g.

<u>CASE WRITER'S NOTE</u>

This abstract from the test report shows the test method, the loadings, and the measured deflections. The remainder of the report extrapolates the results to deflections to be expected in a fully assembled four module house and determines the stresses in the principal steel structural elements corresponding to test loads and deflections.

EXHIBIT B-1

ACTUAL DEAD WT. MODULES AS TESTED; 11'-7½ × 20' MODULES

UPPER MOD;	SHEATH 3/8" 1.5 PSF × 15' × 20'	=	450	LBS /MOD
	TRUSSES 73 # ea × 11	=	800	" "
	12" [, ROOF 64' × 9.4	=	600	" "
	BLOCKING @ ROOF 104' @ 1 #/'	=	104	
	EXT WALL @ AIRBAG			
	2×4 STUDS + 3/8" PLY 2 PSF × 7 × 20	=	280	" "
	COL'S 4×9 × 8.5	=	306	" "
	12" [FLOOR 64' × 9.4	=	600	" "
	K-BMS 4×11' × 5.5	=	240	" "
	1⅛" PLY 4 PSF × 240	=	960	" "
	4×8 WALL PANELS @ 2 PSF		128	
			4448	LBS

WT/SF = 4448/240 = 18.6

LOWER MOD: SAME AS UPPER, EXCEPT NO ROOF : 4448 − (450+800+104) = 3094 LBS " " = 12.8

. TOT DEAD WT MODULES 7542 AVE WT/SF 15.7

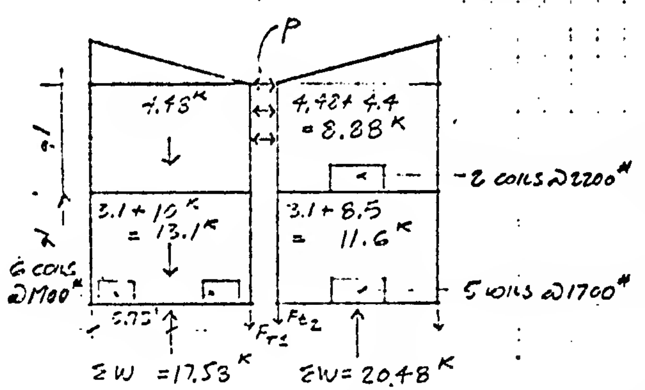
DEAD WT FULLY CONSTR MODULES

10.6^K (44 PSF)

7.7^K (32 PSF)

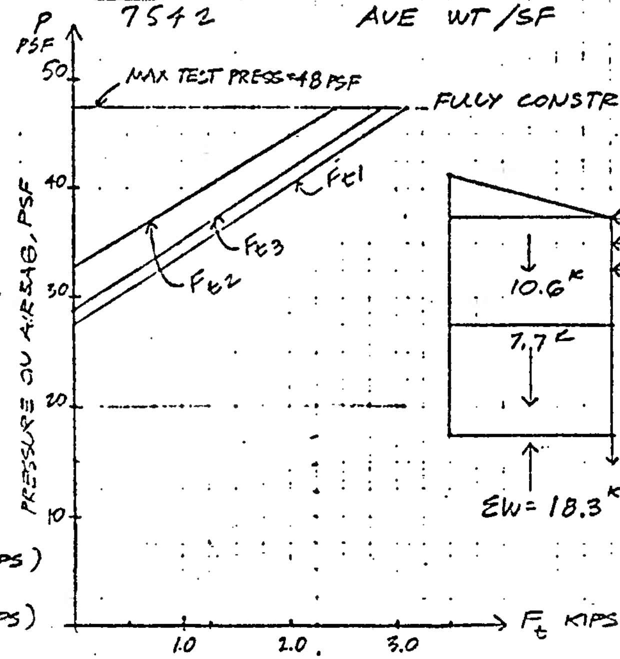
(33 PSF)

TEST SETUP WITH COILS ADDED



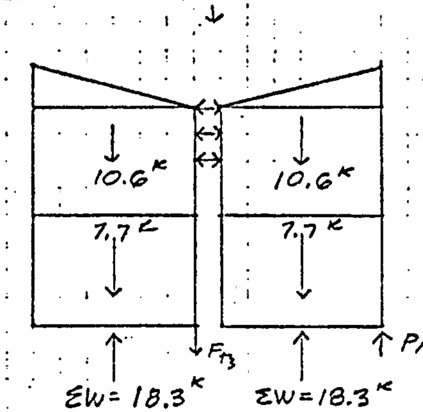
$2F_{t_1} = (3.6\,p - 17.58 \cdot 5.75)/11.5 = 0.314\,p - 8.8$ (KIPS)

$2F_{t_2} = (3.6\,p - 20.48 \cdot 5.75)/11.5 = 0.314\,p - 10.2$ (KIPS)



UPLIFT ON TIE-DOWNS AS FUNCTION OF TEST PRESSURE

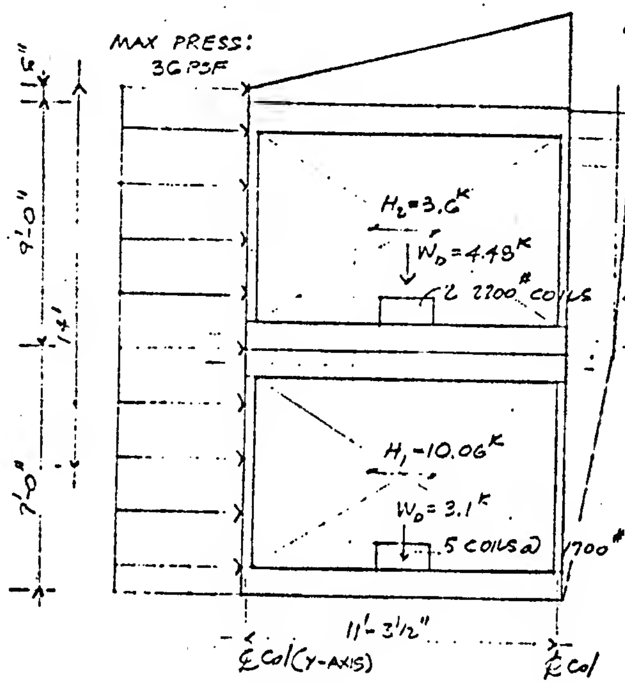
FULLY CONSTRUCTED MODULES



$2F_{t_3} = 0.314\,p - 9.15$

EXHIBIT B-1 (continued)

TEST OF PURE FRAME. :



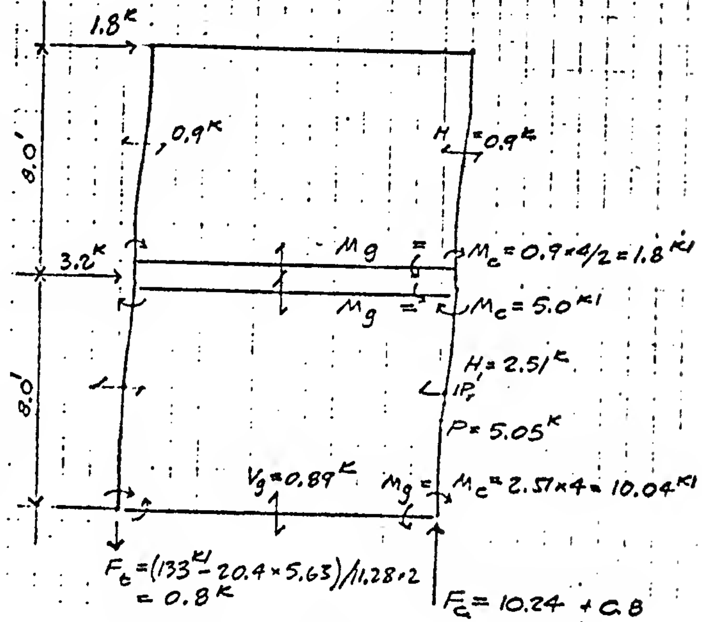
TOTAL LOAD ON TEST STR

$H_1 = 36\ PSF \times 14' \times 20' = 10.06^K$
$H_2 = 36\ '' \times 5.0 \times 20' = 3.6^K$

$\Sigma W_{UPPER\ MOD} = 4.48 + 4.40 = 8.88^K$

$\Sigma W_{LOWER\ MOD} = 3.1 + 8.5 = 11.6^K$
$\Sigma W_{TOT} = 20.48^K$

$M_o = 36 \times 18.5 \times 20 \times 10 = 133^{K'}$
$P_o = 133/11.28 = \pm\ 11.8^K$



FORCES ON FRAME

P_{MAX} ON LOWER COL: $11.04 - (0.89 + \overset{5.99}{20.43/4})$
$= 5.05^K$

$M_y = M_c = 5.0^{K'}$
M_x : APPROX DEAD WT FLOOR:

PLY	960 #
K-BMS	240 #
FL C	600 #
"	600 #
EXT WALL	280 #
	2680 #

$M_{x\ DEAD\ SS}$: $2.680 \times 20/8 = 6.7$
% of SSBM @ ENDS
M_x DEAD @ COL $= 0.21 \times 6.7 = 1.41^{K'}$
M_x COILS $= P \cdot 1' =$ $2.2^{K'}$
$3.61^{K'}$

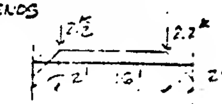
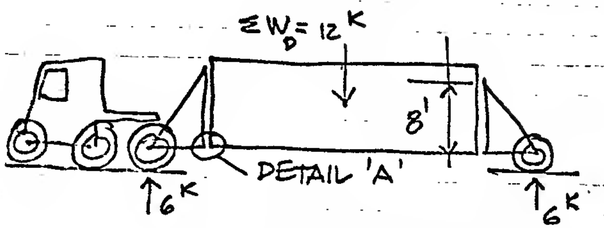


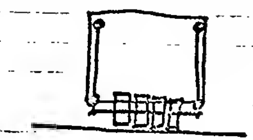
EXHIBIT B-1 (continued)

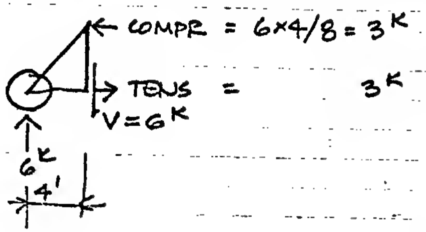
T-1

TRANSPORTATION STRESSES:

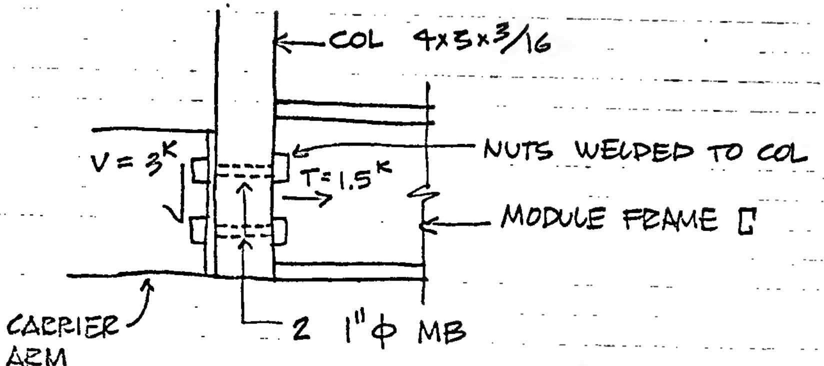
METHOD OF CARRYING MODULES







DETAIL A:



SHEAR ON BOLTS : $f_s = \dfrac{3^K}{2 \times \pi/4} = 1.8\ ksi$

TENSION ON " : $f_t = \dfrac{1.5}{2 \times \pi/4} = 0.9\ ksi$

T-2

NOTE: TESTS CARRIED OUT IN FIELD INCLUDED THE FOLLOWING:

1) PANIC STOP (REAR TIRES LOCKED & BURNING)

ESTIMATED ACCELERATION: $\approx 50\%\, g$ (HORIZONTAL)

2) DRIVING OVER ROUGH TERRAIN (DIFFICULT TO REMAIN STANDING IN MODULE WITHOUT HOLDING ON TO WALL)

ESTIMATED VERTICAL ACCELERATION: $\approx 100\%\, g$

\+ HORIZONTAL $\approx 50\%\, g$

3) SUDDEN START (POPPING CLUTCH @ FULL THROTTLE)

4.) FULL SPEED OF 50 MPH ON HIGHWAY FOR SUSTAINED PERIODS -

ALL OF ABOVE RESULTED IN NO DAMAGE TO ANY STRUCTURAL OR ARCHITECTURAL OR MECHANICAL ELEMENTS,

DIFFICULTIES WITH MODULAR HOUSING (C)

After he submitted his revised calculations, Aharon Klein received a telephone call. It was a checker for the Department of State Housing and Regional Planning. "You probably don't remember me, Mr. Klein, but I remember you," he said. "You interviewed me when I applied for a job when I graduated. I didn't get the job." Aharon couldn't remember the incident but thought, "Since this man knows me, he knows I can do much more complicated designs than this. I should have no trouble getting approval."

As the conversation developed, it turned out that the state checker had a large number of questions to be answered in greater detail than on the submission. Among his other concerns was what effects cut-out holes (Exhibit C-1) in the members would have. Aharon and the checker argued about the radius at the corner of the holes and its effect on the stability of the members. The checker finished by asking for more computations. Aharon recalls, "I finished with the feeling that this guy was determined to make me work for my approval. By the time I got the approval, I had made twice the computations I felt were necessary and had first submitted."

When his revised calculations came back with still further information required, Aharon went to see the Chief Structural Engineer for the Department. After considerable discussion, Aharon finally said, "Look, if you don't give me approval pretty soon, I'll just go ahead and do another test. The units are built and the law states that when the engineers can't agree on the design based on computations a test will be made." Aharon wanted an end to the delay.

The Chief Structural Engineer outlined his position: the department wasn't set up to handle tests and they believed that computations were more reliable and conservative than tests, the exact opposite view to that of the F. H. A. He elaborated, "I know that anything that's designed according to the building code is O. K. The code values are very conservative."

The outcome of that meeting was a compromise. Omega did not do another test. The Department accepted some of the conclusions based on the original test. Aharon submitted some further computations and approval was given based upon these.

Even with approval of his original design, Aharon was still faced with problems in getting further approvals. He had

originally hoped to get approval on his basic 12 ft x 9 ft x 30 ft module and subsequently to receive automatic approval on any shorter units. The immediate response was, "No, you can't do that. We're not set up to do it that way. You have to submit drawings for each different plan you propose to use." The Department was simply not prepared to approve a building system. Each different floor plan had to be submitted and approved on its own merit as a separate entity.

Nothing could be done about this. Aharon went back and started submitting plans as fast as the orders came in. They were immediately returned. The Department did not wish to check three or four plans from one company at one time. They instructed Omega to submit one plan at a time. Only after they received approval on one plan could they submit another plan. This put them once more at the end of the waiting line.

This has greatly inhibited the flexibility of the modular building concept because as business developed they had developers coming in every day, each with a slightly different requirement. Omega could easily satisfy the requirements from production, but if it was not a standard floor plan, already approved, they were faced with a six to eight week delay in getting approval. They have had to give up projects they could easily have fulfilled because the developer wanted the project completed in two months. Since developers are accustomed to getting what they want in housing construction, it is nearly impossible to persuade them to abandon their plans in favor of a standard floor plan already approved.

This limitation on the flexibility of using modular housing is being continually negotiated with the Department of State Housing and Regional Planning and some progress is being made. As experience is gained with the use of modular systems, this problem should eventually resolve itself. Looking on the positive side, Aharon states, "On the other hand, with departmental approval, we can sell our units anywhere in the state. Local authorities cannot turn it down and as we get more models approved, we will have a greater range of units from which a developer can choose."

Today (1972) Aharon Klein looks forward to a successful and expanding business. "We're over our engineering problems. Most of our problems now are production, installation, and marketing."

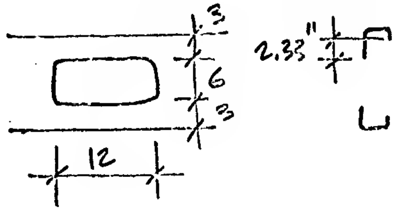
"Our present production costs are just about equal to conventional building costs. We are, therefore, concentrating on lowering costs by improving our production techniques and by taking advantage of larger volume production. We

find that most of our business is with developers and we're set up to produce in quantity. We try to arrange our orders so that we are producing more than 100 of any given module at one time. The recent trend toward two-story town houses has been to our advantage. Our basic four module, two, three, and four bedroom house fits both the town house concept and our production requirements.

"We're still faced with the continual problem of convincing communities that factory built homes are not mobile homes or prefabricated homes. Because of previous experience and bad publicity, people don't like the idea of having prefabricated housing in their neighborhood because they think that it will lower their property values. We have to spend a lot of time and effort demonstrating to these people that our modular system homes are quality homes and that they will be an asset to the community. We haven't failed to convince anyone yet."

SUMMARY : PROPERTIES OF BMS @ HOLES

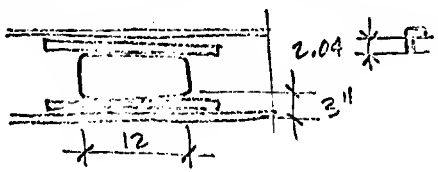
'A' TYPE UNREIF.



$I = 0.747\ in^4$

$I_T = 53.8\ in^4$

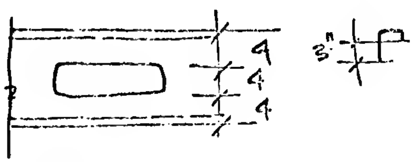
'A' TYPE REIN



$I = 1.394\ in^4$

$I_T = 59.1\ in^4$

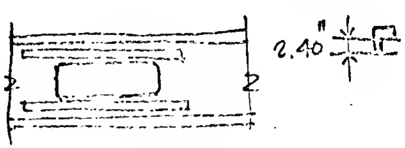
'B' TYPE UNREINF



$I = 1.10\ in^4$

$I_T = 55.5\ in^4$

'B' TYPE REINF



$I = 2.283$

$I_T = 56.65$

6A-2

'A' UNREINF

① f_b:

$M = 2^{KI}$

$f_b = \frac{2 \cdot 12 \cdot 6}{53.8} = 2.7$ ksi

$f_{b\,shear} = 0 \quad \frac{0}{2.7\ ksi} < 24$ OK

② 'B' UNREIF

$M = 4^{KI}$

$f_b = \frac{4 \times 12 \times 6}{55.5} = 5.2$ ksi

$f_{b\,shear} = \frac{1.0 \times 6 \times 3}{1.10} = \frac{16.4\ ksi}{21.6} < 24$ ksi OK

③ 'B' UNREIF

$M = 8^{KI}$

$f_b = \frac{8 \times 12 \times 6}{55.5} = 10.4$ ksi

$f_{b\,shear} = \frac{0.37}{2} \times 6 \times \frac{3}{1.1} = \frac{3.0\ ksi}{13.4\ ksi} < 24$ OK

④ 'B' UNREIF

$M = 2.0^{KI}$

$V = 1.7^{K}$ < ② above so OK

EXHIBIT C-1

6A3

① 'B' UNREIF

$M = 0$

$f_b = 0$

$f_b\ shear = 1.0^k \times \frac{6 \times 3}{1.1} = 16.5\ ksi < 24$ OK

② 'B' UNREIF

$M = 0$

$f_b = 0$

$f_b\ shear = \frac{2.5^k}{2} \times \frac{6 \times 3}{1.10} = 20.5\ ksi < 24$ OK

③ 'B' UNREINF

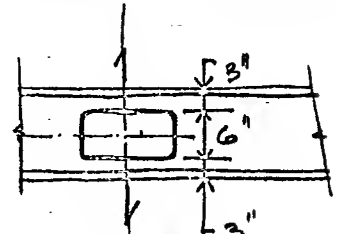
$M = 8^{k'}$

$f_b = \frac{8 \times 12 \times 6}{55.5} = 10.4\ ksi$

$f_b\ shear \cong \frac{0.0}{10.4} < 20$ OK

EXHIBIT C-1 (continued)

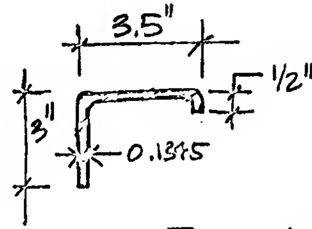
"A" OPNG - BEDROOM MODULE 6-B



$\Sigma V = 0.7^k$

SHEAR STRESS: $\frac{0.7}{2 \times 0.1345 \times 3} = 880\ psi < 7900$ allow $\left(\frac{h}{t} = 90\right)$

OK



$A = 3 \times 0.1345 = 0.40$

$3.36 \times 0.1345 = 0.45$

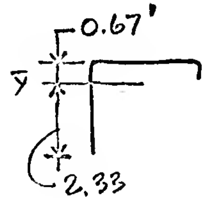
$0.5 \times 0.1345 = 0.07$

$\qquad 0.92$

$\bar{y}: 0.40 \times 1.5 = 0.600$

$0.07 \times 0.25 = 0.018$

$\qquad 0.618 \div 0.92 = 0.67$



$I: 2.33^3 \times 0.1345/12 = 0.140$

$2.33^2 \times 0.1345 \times /2 = 0.360$

$0.45 \times 0.67^2 = 0.202$

$0.67^2 \times 0.1345/2 = 0.030$

$0.67^3 \times 0.1345/12 = 0.003$

$0.07 \times 0.42^2 = 0.012$

$\qquad 0.747\ in^4$

$f_b = \frac{0.35^k \times 6'' \times 2.33}{0.747} = 6.6\ ksi$

$f_s = \frac{2^k \times 12.6''}{} = 2.6\ ksi$

$+ \Big\} < 20\ ksi$ OK ∴ HOLE IS OK

6 B 1

REDUCTION IN I DUE TO 6" HOLE:

I: 0.1345" 6" $= 0.1345 \times 6^3/12 = 2.4 \text{ in}^4$

CORRECTED I: $56.2 - 2.4 = 53.8 \text{ in}^4$

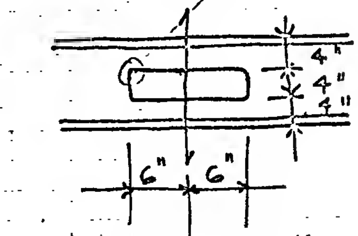
$f_{a_{OLD}} = \dfrac{2 \cdot 12 \cdot 6}{56.2} = 2.6$

f_a CORRECTED $= \dfrac{2 \times 12 \times 6}{53.6} = 2.75$

$f_b = \quad \dfrac{6.60}{9.35}$ Ksi < 20 OK

6-C

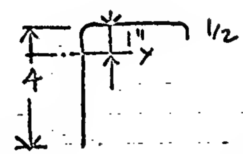
"B" - OPNG — check local buckling — BEDROOM MODULE



$\Sigma V = 0.37^K$

SHEAR STRESS $= \dfrac{0.37}{2 \times 4 \times 0.134} = 350$ psi < 7900 allow $\left(\dfrac{h}{t} = 90\right)$

OK



$A = 4 \times 0.1345 \quad 0.54$
$3.36 \times 0.1345 = 0.45$
$0.5 \times 0.1345 = \underline{0.07}$
1.06

$\bar{y} = 0.54 \times 2 = 1.08$
$0.07 \times 0.25 \quad \underline{0.018}$
$1.098 \div 1.06 = 1"$

$I \leq 3^3 \times 0.1345/12 = 0.30$

$3^2 \times 0.1345/2 = 0.60$

$0.45 \times 1^2 = \underline{0.20}$
1.10 in^4

$f_b = \dfrac{0.37}{2} \times \dfrac{6" \times 3}{1.10} = 3.0$ Ksi

$f_a = \dfrac{8.0 \cdot 12 \cdot 6}{56.2} = \dfrac{10.3 \text{ Ksi}}{13.3} < 20$ Ksi OK

reduce ∴ 56.2

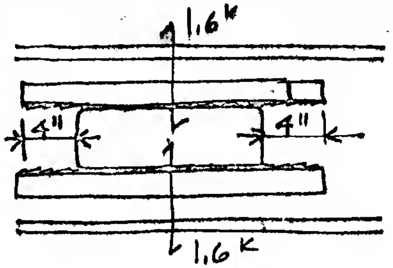
HOLE IS OK

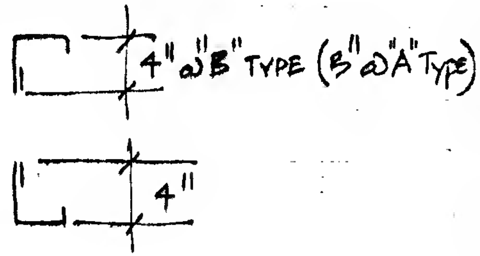
$I = 56.2 - 4^3 \times 0.134 = 56.2 - 0.71 = 55.49$

EXHIBIT C-1 (continued)

"B" Type OPNG - LIVING RM MODULE

6-D





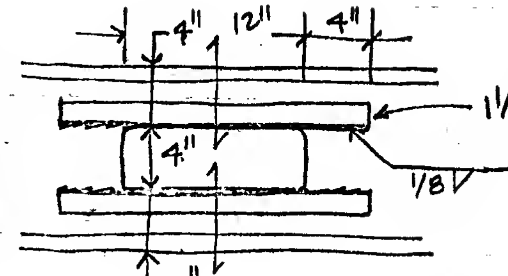
NOTE: THIS OPNG IS STRESSED LOWER THAN "A" TYPE UNDER THE SAME SHEAR - SEE PG 6-H

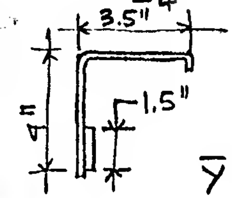
∴ OK

Show calcs.

'B' TYPE OPNG - REINF

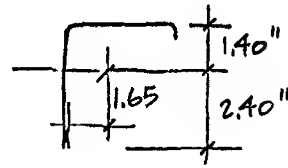
PG 6-D-1



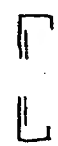


$$A = \begin{aligned} 4 \times 0.1345 &= 0.5350 \\ 1.5 \times 0.125 &= 0.1900 \\ 3.5 \times 0.1345 &= 0.4500 \\ 0.5 \times 0.1345 &= \underline{0.0700} \\ &\quad 1.2450 \text{ in}^2 \end{aligned}$$

$$\bar{y}: \begin{aligned} 0.53 \times 2 &= 1.060 \\ 0.07 \times 0.25 &= 0.018 \\ 0.190 \times 3.35 &= \underline{0.640} \\ &\quad 1.718 \quad \div 1.245 = 1.40'' \end{aligned}$$



$$\begin{aligned} 2.40^3 \times 0.1345/12 &= 0.155 \text{ IN}^4 \\ 2.40 \times 0.1345 \times 1.2^2 &= 0.460 \text{ "} \\ 1.40^3 \times 0.1345/12 &= 0.031 \text{ "} \\ 1.40 \times 0.1345 \times 0.7^2 &= 0.092 \\ 1.5^3 \times 0.125/12 &= 0.035 \\ 0.19 \times 1.65^2 &= 0.520 \\ 0.45 \times 1.4^2 &= 0.880 \\ 0.07 \times 1.25^2 &= \underline{0.110} \\ &\quad 2.283 \text{ IN}^4 \end{aligned}$$



$$I_c = 56.2 - 2.4 + 0.125 \times 1.5 \times 2.75^2 \times 2$$
$$= 56.65 \text{ IN}^4$$

EXHIBIT C-1 (continued)

INSTRUCTOR'S NOTES

"Difficulties with Modular Housing"

This case deals with the problems of introducing an innovative form of residential housing. The problems are both technical and managerial. The housing system discussed was conceived and developed as a complete system that provides attractive housing yet offers cost advantages in production, transportation, and erection. But technical competence is not enough. The principal problem becomes one of satisfying the various regulatory bodies that the innovative methods of construction are as good as the more traditional methods.

The case is in three parts, the first two parts ending at a critical decision point. Following are some questions that might be answered or discussed by the students after studying each section:

Part A

- What are the merits of the proposed modular housing system?
- What are the advantages and disadvantages of industrialized housing?
- Prepare a preliminary flow chart for assembling a typical module.
- Determine the strength of the steel frame under lateral and vertical loading.
- What would be deflection of the steel module due to a wind load of 30 lb/ft^2?
- The case mentions transporting the module by truck. Design a test procedure for testing the module to ensure that transportation damage will not occur.
- The F. H. A. required a test of a full size house. Design a test procedure describing the method of loading and measurements to be made.

Part B

- Compare your test proposals with the tests carried out by Aharon.
- Using the test results on the full scale module determine the deflections to be expected in a four module home.
- Determine the actual stresses in the vertical steel members due to 30 lb/ft^2 and 50 lb/ft^2 tests.
- If material had been exactly to specification would the design have been satisfactory?
- How valid were the tests in proving out the design?
- Should the design have been approved on the basis of these tests?

Part C

- What do you think of the State Housing Authority's comment about not relying on tests?
- What shortcuts did Aharon expect to achieve in getting approvals? Which of these were not realized? Why?
- Were the cautions on the part of the state authorities justified?
- Do you approve of the way Aharon handled the situation?
- Comment on the calculations on the effect of holes in the structural members.